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(54) **NON-PLANAR SURFACE PROJECTING SYSTEM, AUTO-CALIBRATION METHOD THEREOF, AND AUTO-CALIBRATION DEVICE THEREOF**

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G06T 7/50 (2017.01)

(52) **U.S. Cl.**
CPC ***H04N 9/3194*** (2013.01); ***G06T 7/50*** (2017.01); ***H04N 9/3185*** (2013.01); ***H04N 9/3188*** (2013.01)

(58) **Field of Classification Search**
CPC .. G06T 7/50; G06T 7/521; G06T 7/80; G06T 2207/10024; G06T 2207/10152;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,618,076 B1 9/2003 Sukthankar et al.
7,001,023 B2 2/2006 Lee et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 101321303 A 12/2008
CN 101500172 A 8/2009
(Continued)

OTHER PUBLICATIONS

M. D. Grossberg et al., "Making One Object Look Like Another: Controlling Appearance Using a Projector-Camera System" *Proceedings of the 2004 IEEE Computer Society Conference on Computer Vision and Pattern Recognition* (*CVPR '04*), 2004, 8 pages.
(Continued)

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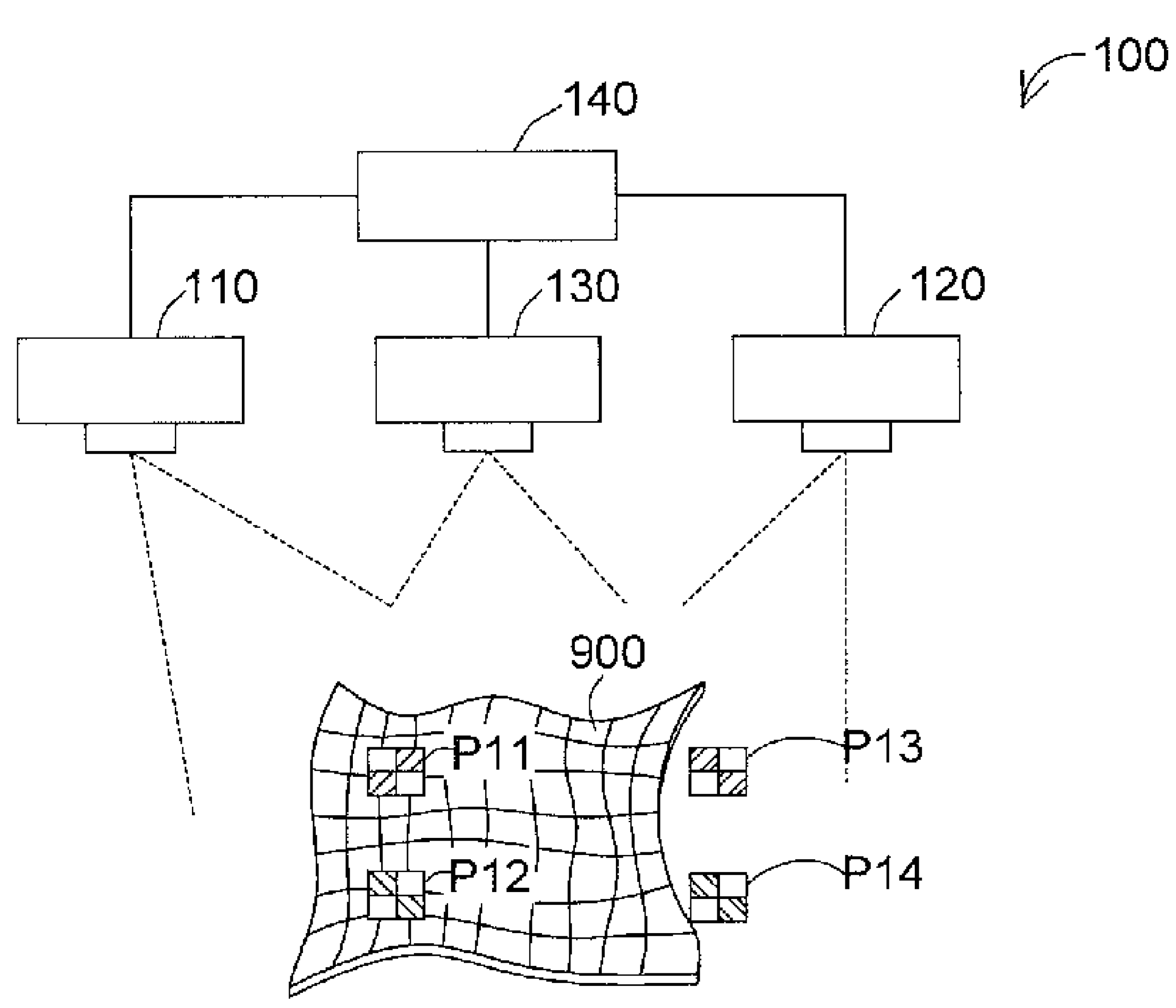
(74) *Attorney, Agent, or Firm* — Muncy, Geissler, Olds & Lowe, P.C.

(57) **ABSTRACT**

A non-planar surface projecting system, an auto-calibration method thereof and an auto-calibration device thereof are provided. In an embodiment of the non-planar surface auto-calibration method, a depth map of a projection surface is measured, a corresponding area corresponding to a projecting area and a depth sensing area is calibrated; and in the corresponding area, an interactive content is adjusted according to the depth map of the projection surface.

24 Claims, 8 Drawing Sheets



(58) **Field of Classification Search**
CPC G06T 2207/30204; H04N 9/3185; H04N 9/3194; H04N 9/3188
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,009,930	B2	8/2011	Li et al.	
8,730,309	B2	5/2014	Wilson et al.	
8,923,562	B2	12/2014	Lin et al.	
9,142,025	B2 *	9/2015	Park	G06T 7/0057
9,716,870	B2 *	7/2017	Sano	H04N 9/3194
2003/0142116	A1	7/2003	Mochizuki	
2009/0086081	A1 *	4/2009	Tan	G01B 11/25 348/333.1
2010/0060803	A1 *	3/2010	Slack	H04N 7/142 348/744
2011/0007283	A1	1/2011	Tanaka	
2014/0168367	A1	6/2014	Kang	
2015/0296192	A1	10/2015	Maeda	

FOREIGN PATENT DOCUMENTS

CN	204929116 U	12/2015
TW	I312100	7/2009
TW	I379147	12/2012
TW	I408489	9/2013
TW	I513313	12/2015
WO	WO 2006/110141 A2	10/2006

OTHER PUBLICATIONS

R. Raskar et al., "Multi-Projector Displays Using Camera-Based Registration" *Proceedings Visualization '99*, Oct. 24-29, 1999, San Francisco, CA, 9 pages.
R. Sukthankar et al., "Smarter Presentations: Exploiting Nomography in Camera-Projector Systems" *Proceedings in International Conference on Computer Vision*, 2001, 7 pages.
M. Kimura et al., "Projector Calibration using Arbitrary Planes and Calibrated Camera", *2007 IEEE Conference on Computer Vision and Pattern Recognition*, 2007, 2 pages.
G. Falcao, et al., "Plane-based calibration of a projector-camera system" *VIBOT Master 9.1* (2008) 12 pages.

* cited by examiner

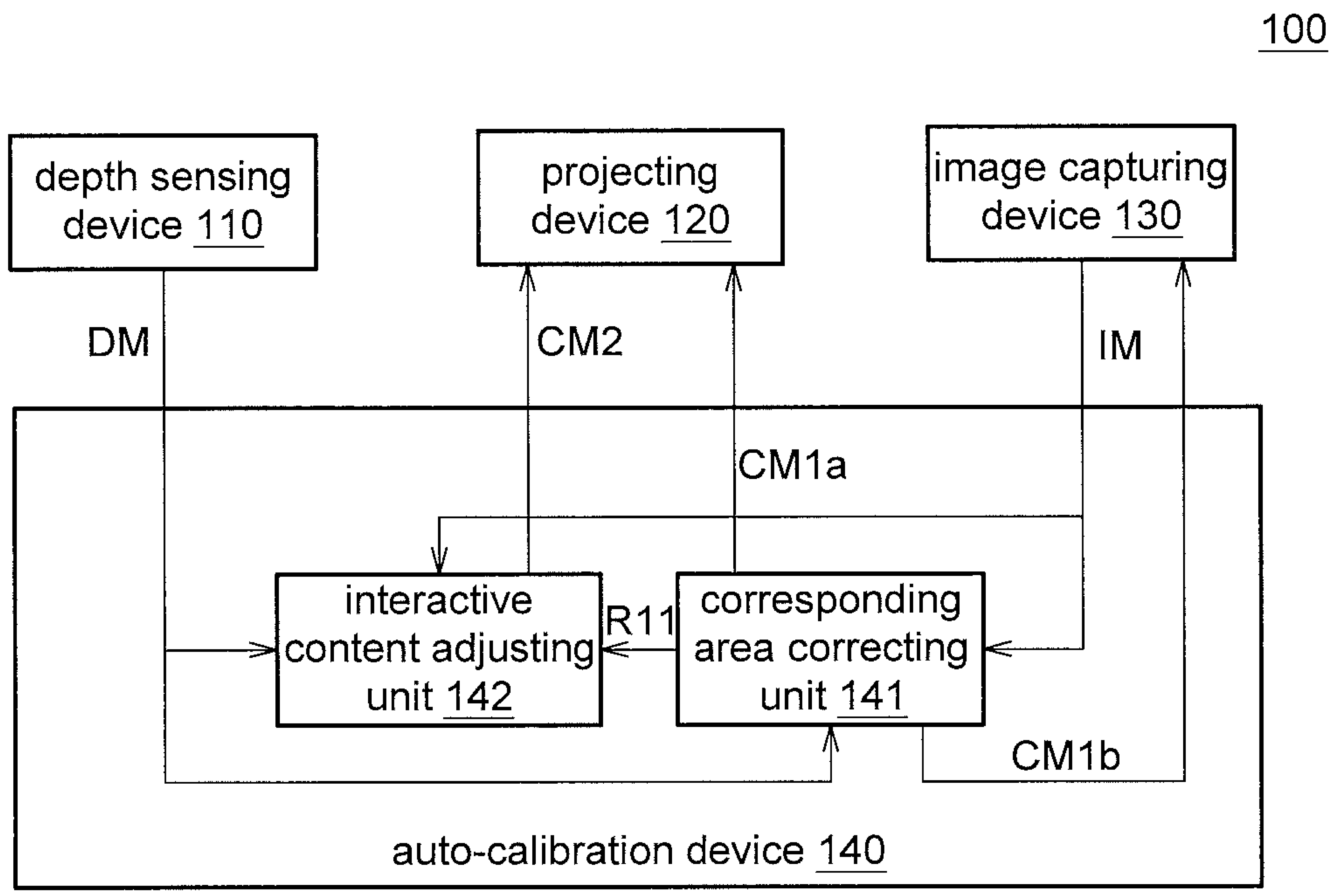

100
depth sensing device 110
projecting device 120
image capturing device 130
DM
CM2
IM
CM1a
interactive content adjusting unit 142
R11
corresponding area correcting unit 141
CM1b
auto-calibration device 140

FIG. 1

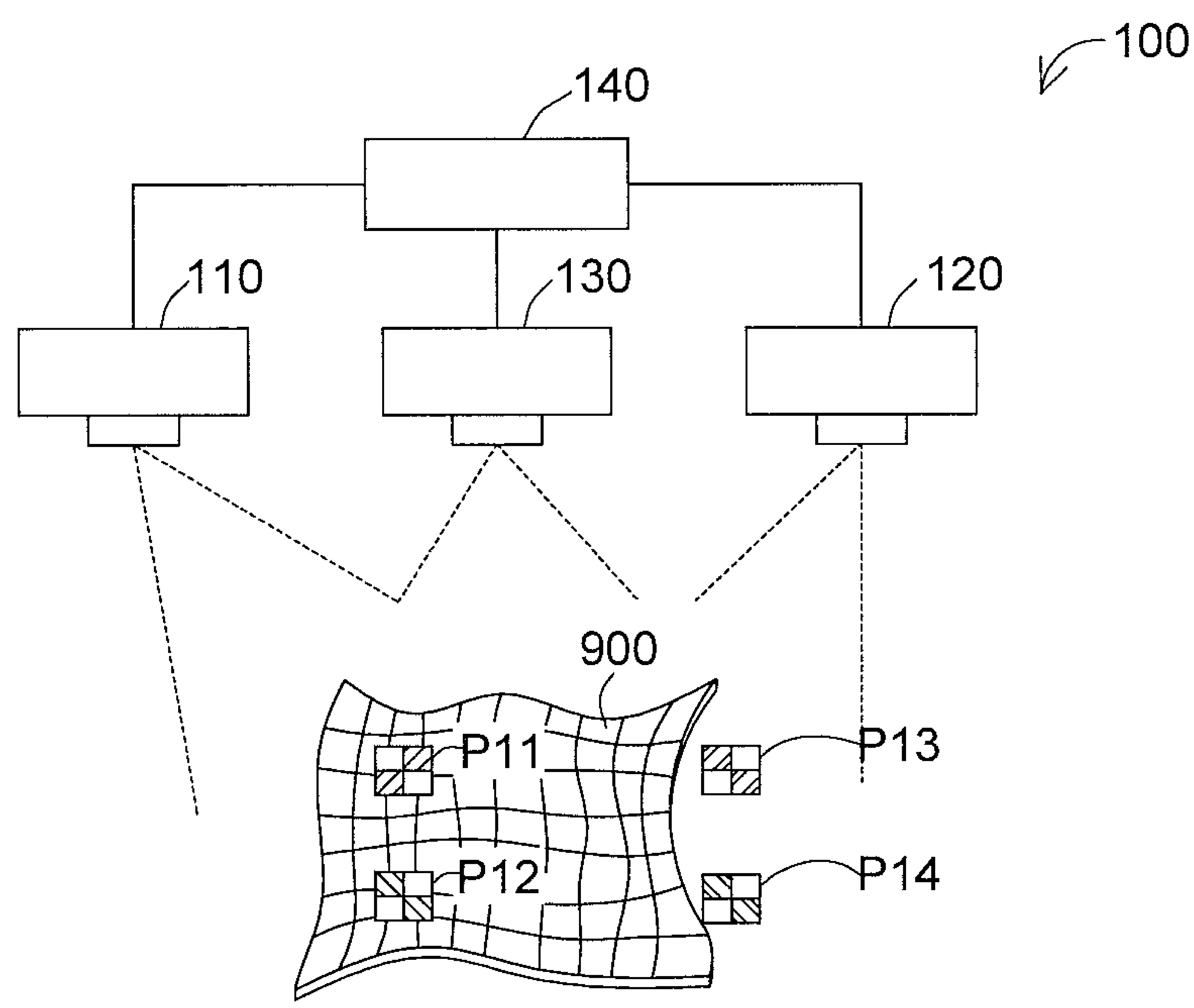

100
140
110
130
120
900
P11
P12
P13
P14

FIG. 2

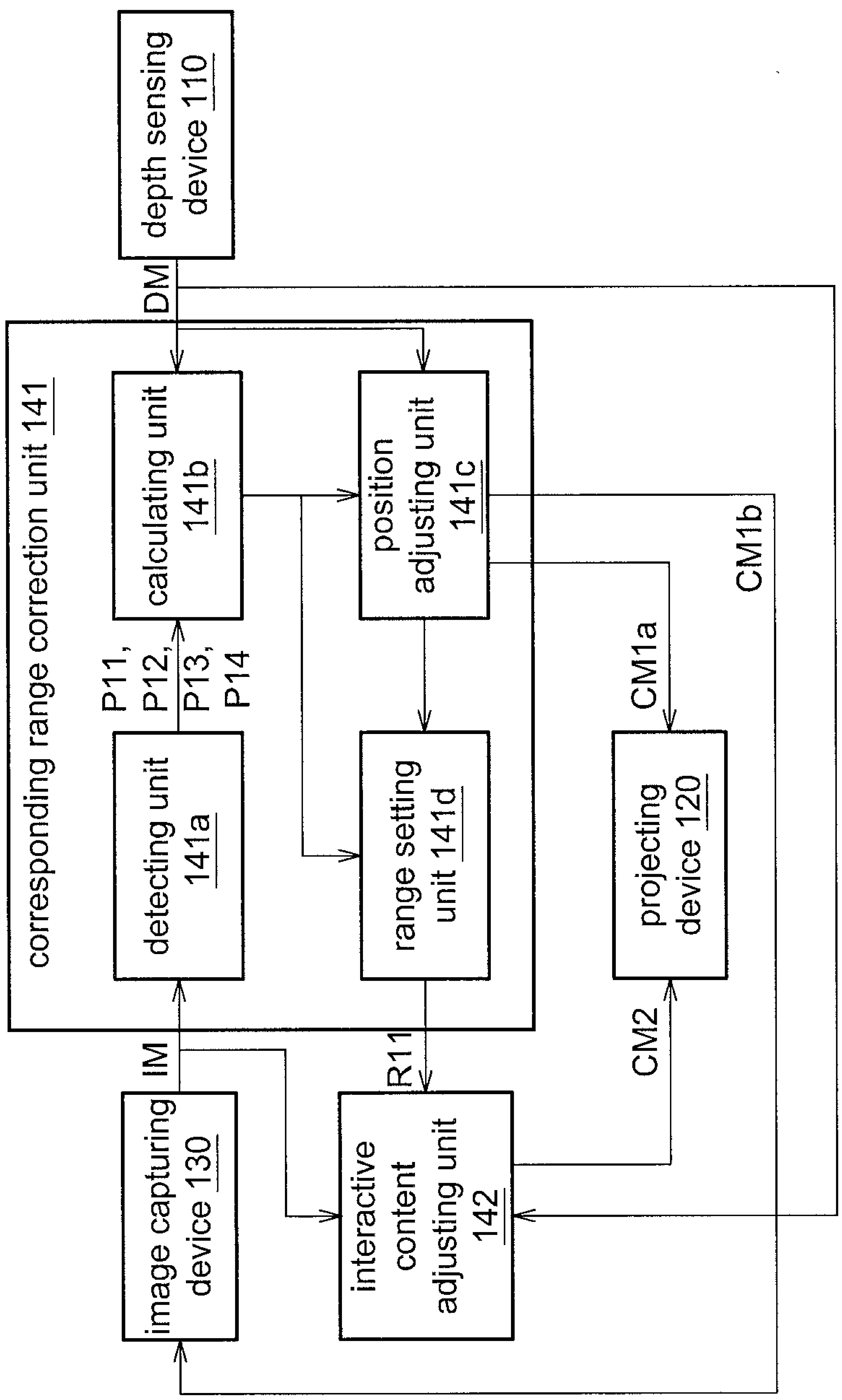

depth sensing device 110
DM
corresponding range correction unit 141
calculating unit 141b
position adjusting unit 141c
detecting unit 141a
range setting unit 141d
P11, P12, P13, P14
CM1a
CM1b
projecting device 120
IM
R11
CM2
image capturing device 130
interactive content adjusting unit 142

FIG. 3

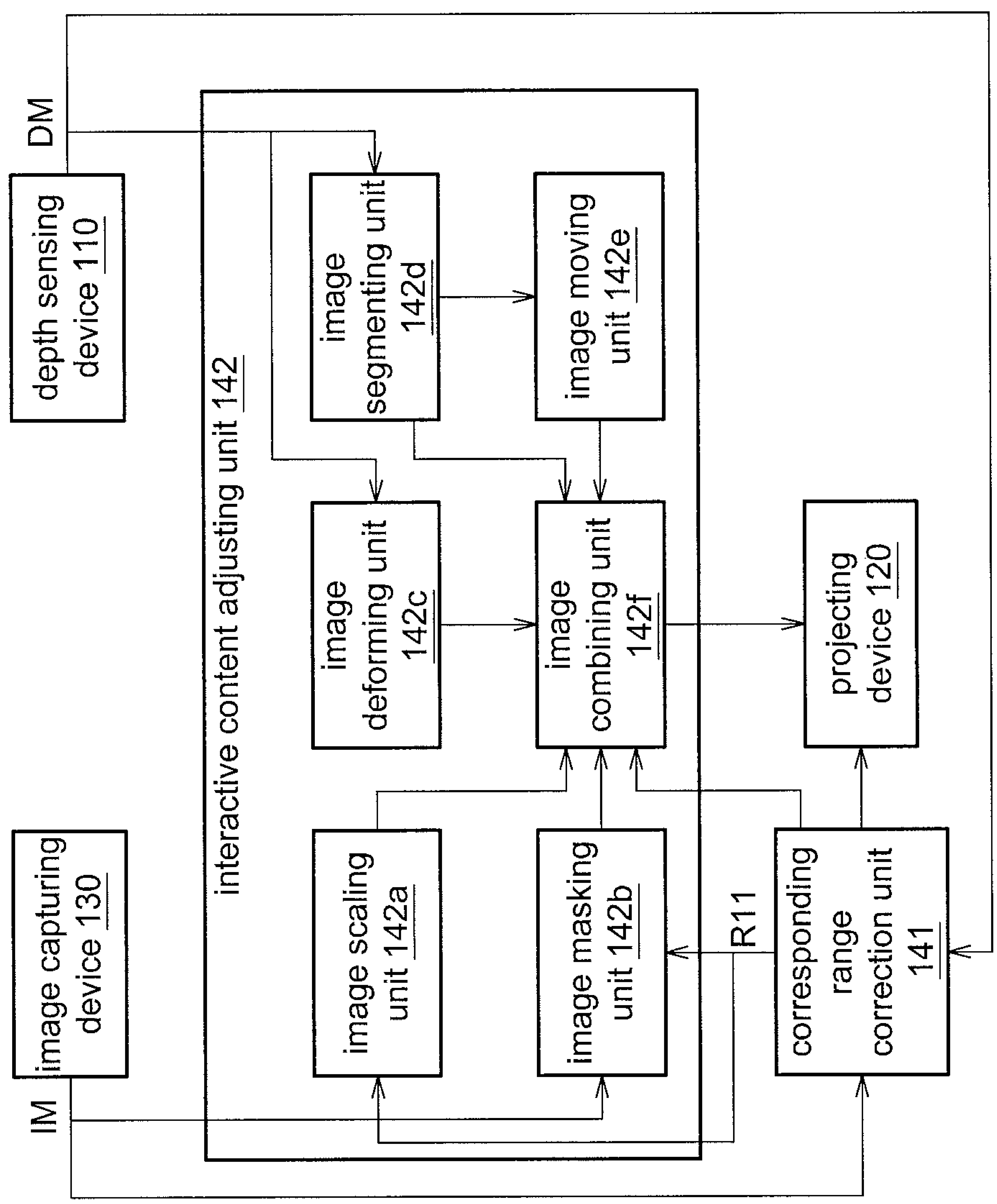

depth sensing device 110
DM
image capturing device 130
IM
interactive content adjusting unit 142
image segmenting unit 142d
image moving unit 142e
image deforming unit 142c
image combining unit 142f
image scaling unit 142a
image masking unit 142b
R11
projecting device 120
corresponding range correction unit 141

FIG. 4

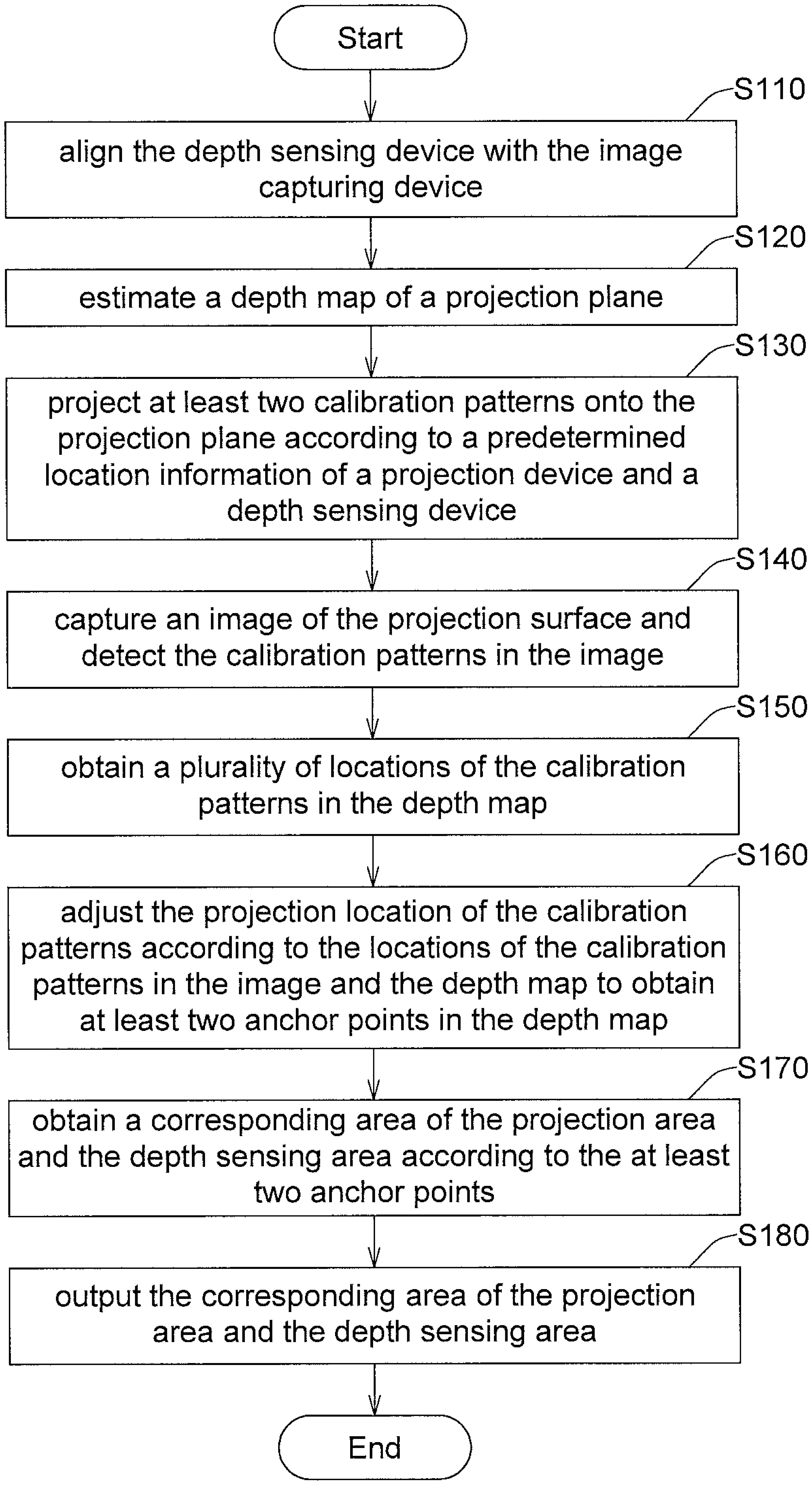

Start
S110
align the depth sensing device with the image capturing device
S120
estimate a depth map of a projection plane
S130
project at least two calibration patterns onto the projection plane according to a predetermined location information of a projection device and a depth sensing device
S140
capture an image of the projection surface and detect the calibration patterns in the image
S150
obtain a plurality of locations of the calibration patterns in the depth map
S160
adjust the projection location of the calibration patterns according to the locations of the calibration patterns in the image and the depth map to obtain at least two anchor points in the depth map
S170
obtain a corresponding area of the projection area and the depth sensing area according to the at least two anchor points
S180
output the corresponding area of the projection area and the depth sensing area
End

FIG. 5

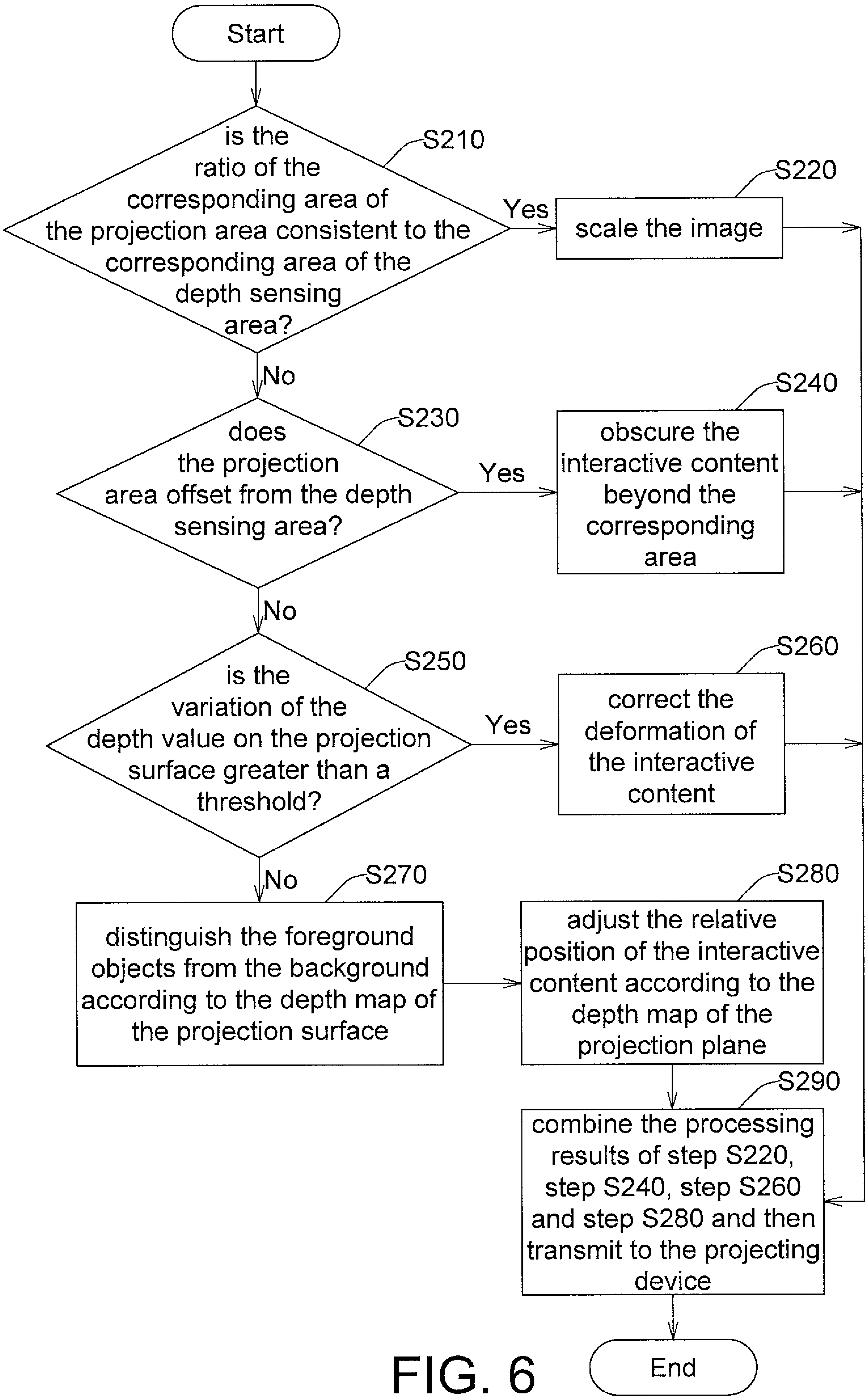

Start
is the ratio of the corresponding area of the projection area consistent to the corresponding area of the depth sensing area?
S210
Yes
scale the image
S220
No
does the projection area offset from the depth sensing area?
S230
Yes
obscure the interactive content beyond the corresponding area
S240
No
is the variation of the depth value on the projection surface greater than a threshold?
S250
Yes
correct the deformation of the interactive content
S260
No
distinguish the foreground objects from the background according to the depth map of the projection surface
S270
adjust the relative position of the interactive content according to the depth map of the projection plane
S280
combine the processing results of step S220, step S240, step S260 and step S280 and then transmit to the projecting device
S290
End

FIG. 6

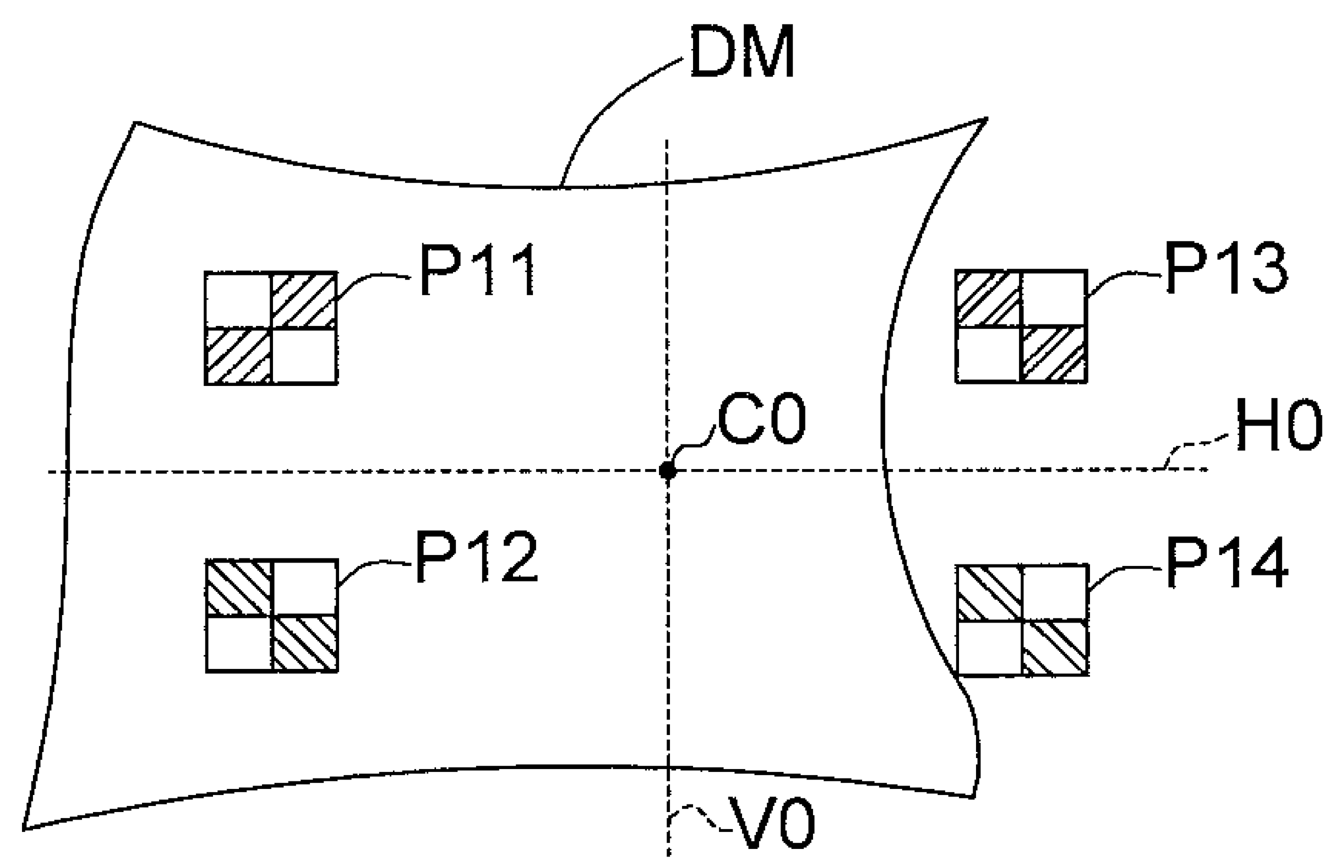


FIG. 7A

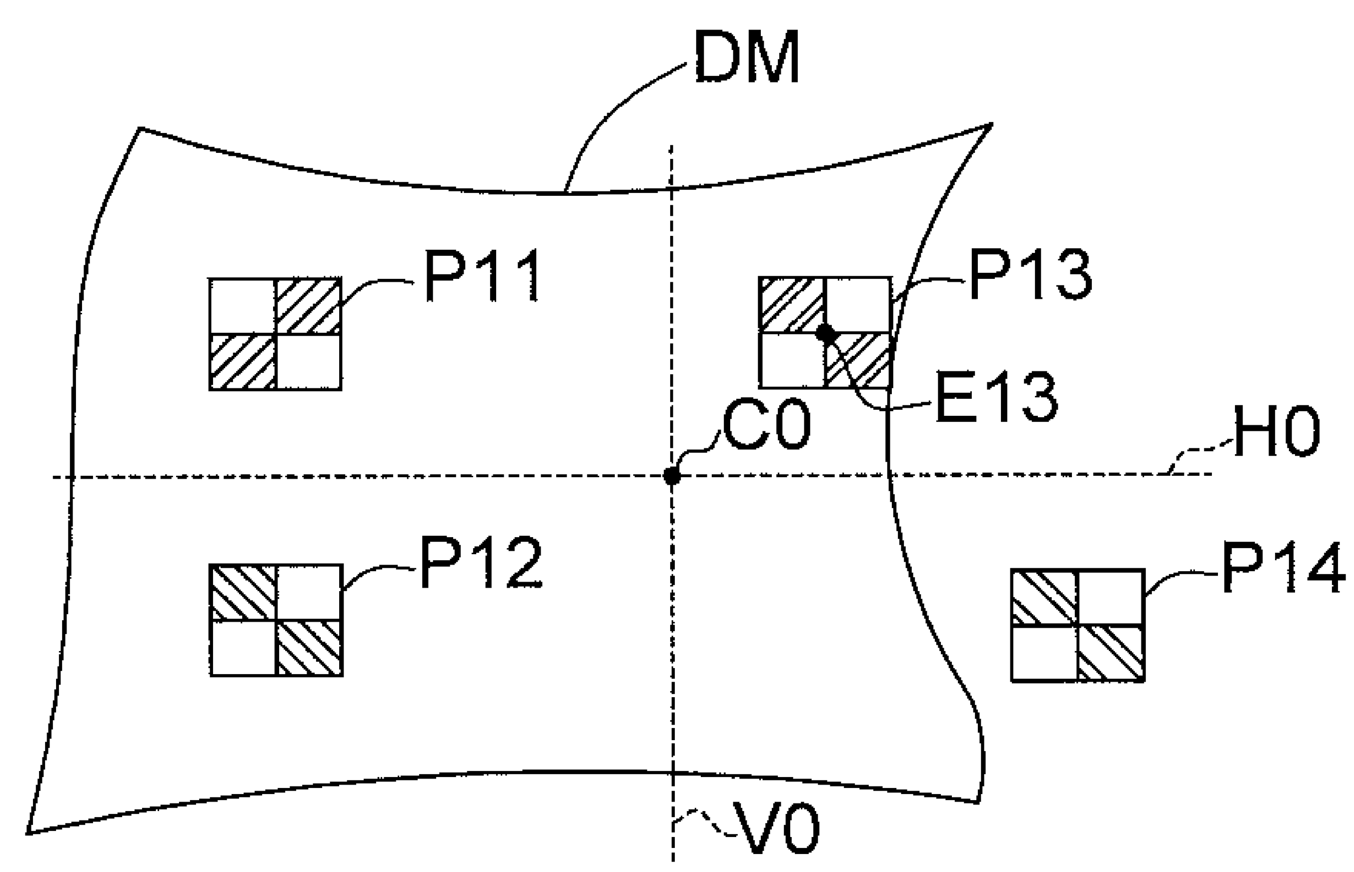


FIG. 7B

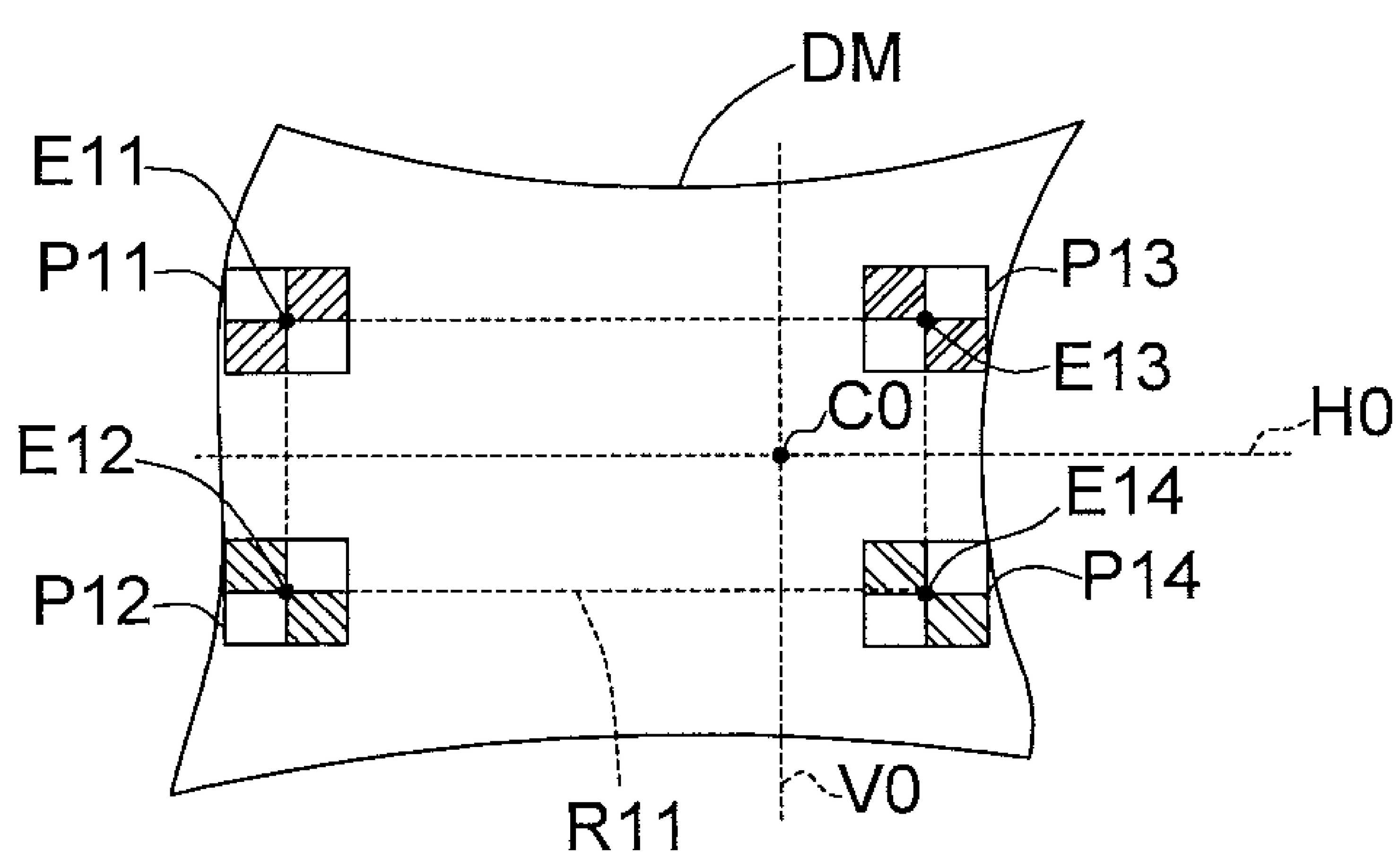


FIG. 7C

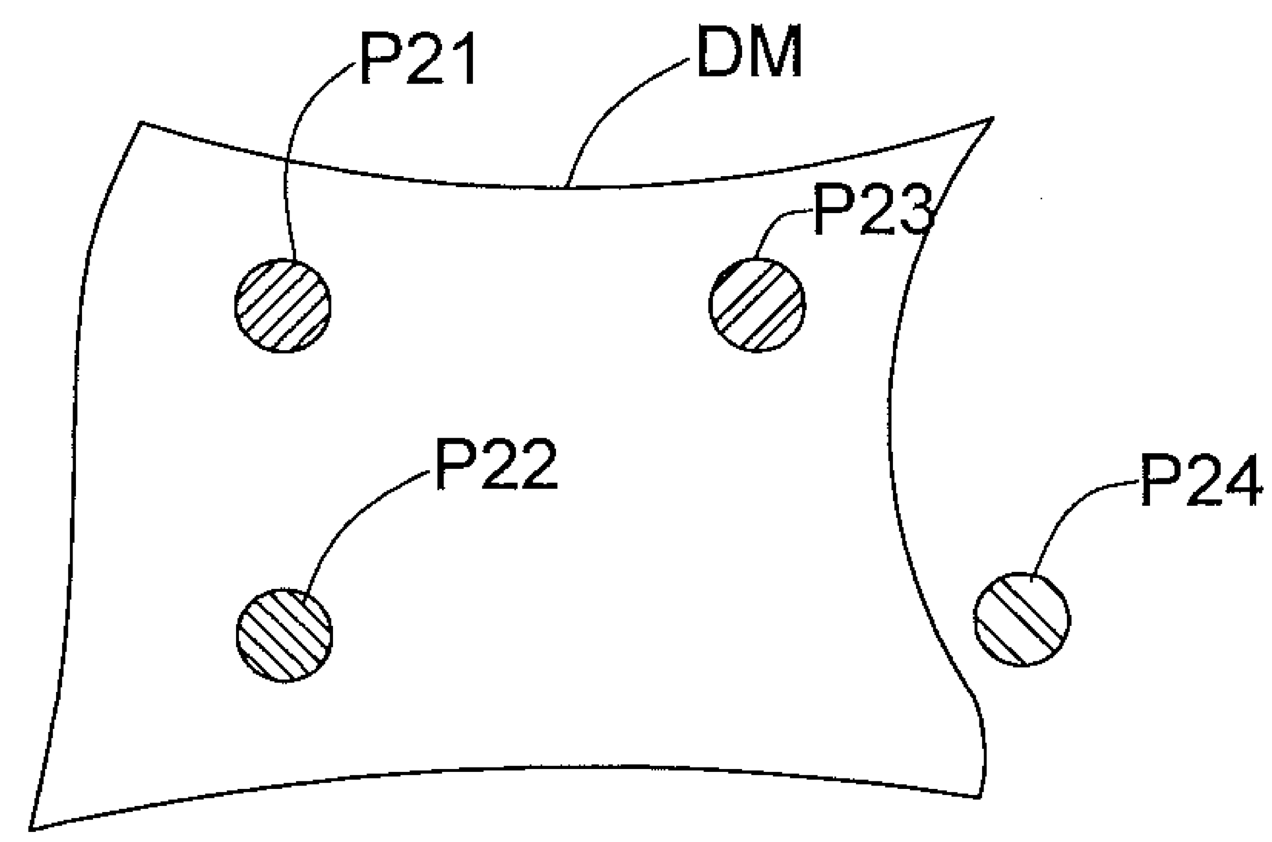


FIG. 8

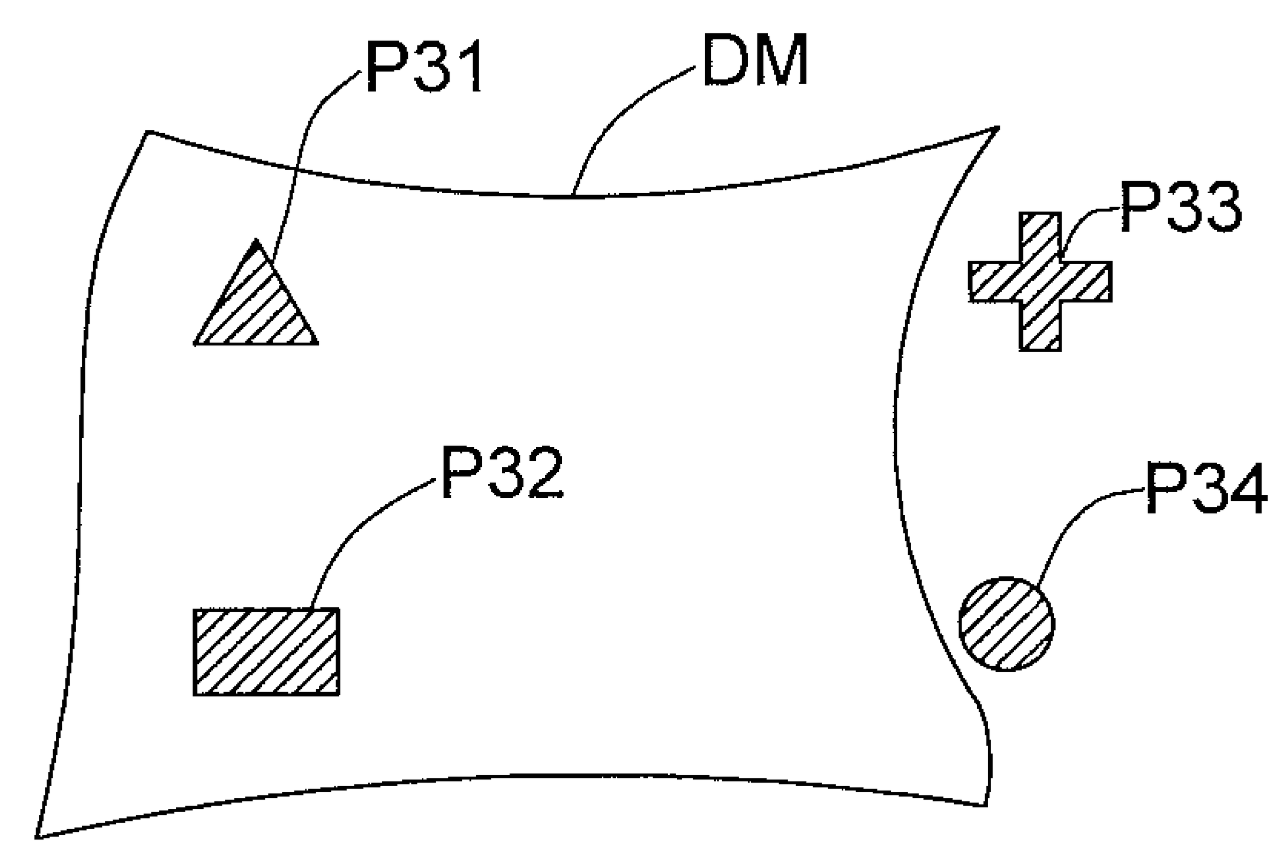


FIG. 9

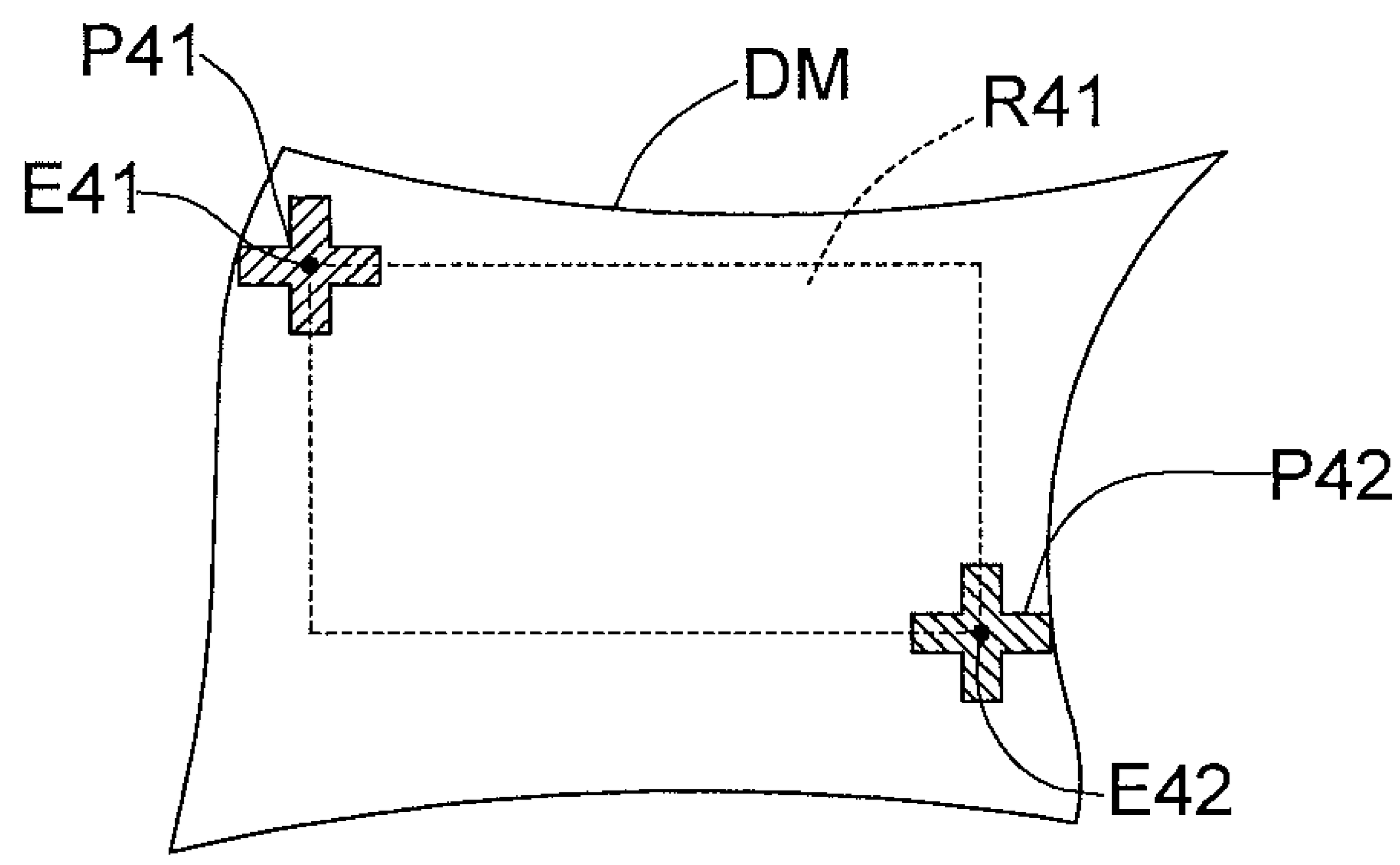


FIG. 10

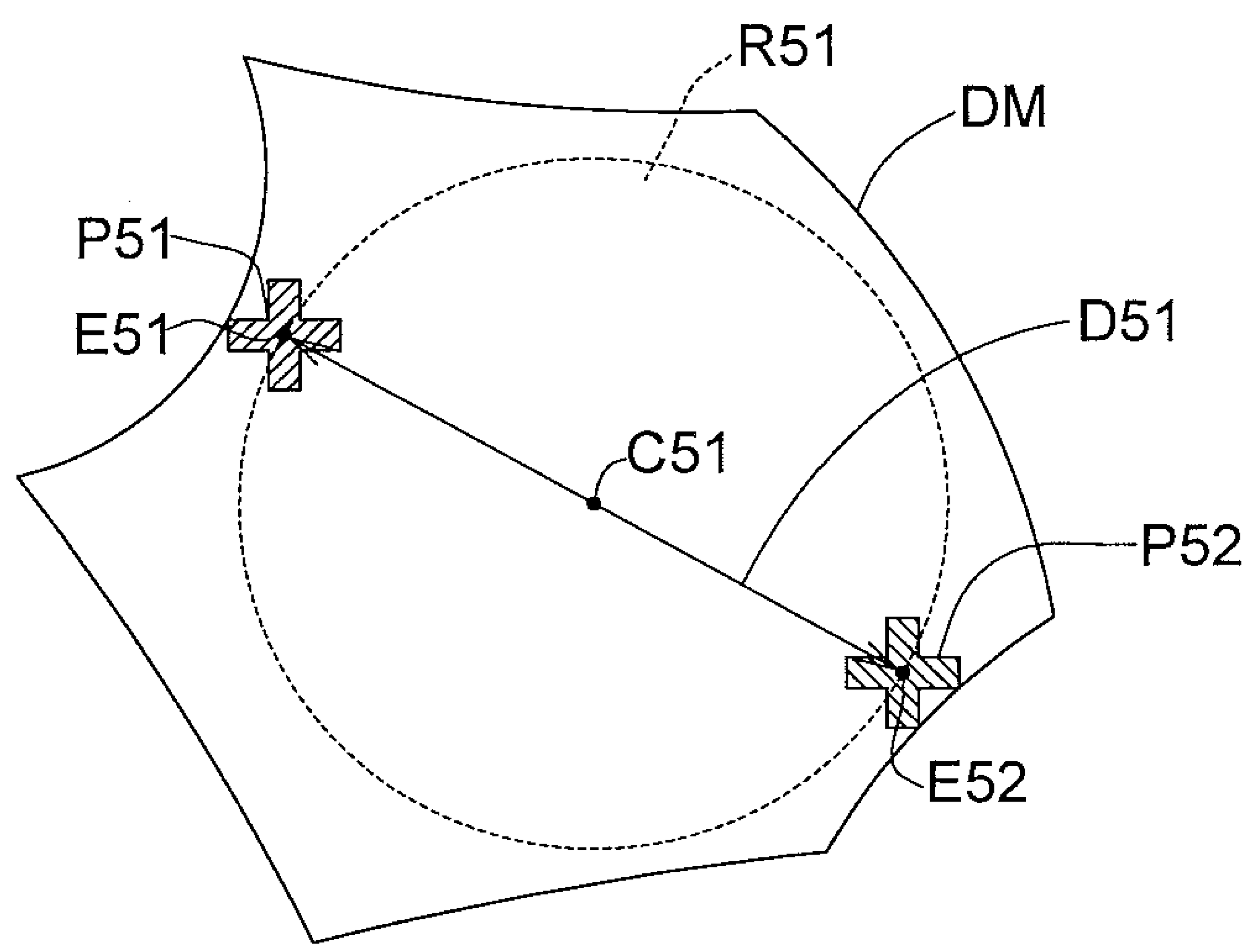


FIG. 11

NON-PLANAR SURFACE PROJECTING SYSTEM, AUTO-CALIBRATION METHOD THEREOF, AND AUTO-CALIBRATION DEVICE THEREOF

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefits of Taiwan application serial no. 105117062, filed on May 31, 2016 and Taiwan application serial no. 106108138, filed on Mar. 13, 2017. The entirety of the above-mentioned patent applications is hereby incorporated by reference.

TECHNICAL FIELD

The technical field relates to a non-planar surface projecting system, an auto-calibration device thereof and an auto-calibration method thereof.

BACKGROUND

Most interactive projectors, such as Epson BrightLink 595Wi and its similar products, have to project images onto a flat surface during calibration. The calibration might fail if the projection surface is not flat enough or is partially covered by some objects. Those projectors could not automatically sense the projection area during calibration, the projection area is manually marked by users instead. Even the professionals need to spend a lot of time in adjusting the projector's position and repeating the calibration steps several times to complete the calibration. Because the calibration is pretty time-consuming, those projectors are usually installed in a fixed position to avoid re-calibration. Such kind of calibration method is not suitable for a portable interactive projection device that moves often.

SUMMARY

According to an embodiment of the disclosure, an auto-calibration method for a non-planar surface projecting system is provided. The auto-calibration method for a non-planar surface projecting system comprises the following steps: estimating a depth map of a projection surface; calibrating a corresponding area of a projection area and a depth sensing area; and adjusting an interactive content within the corresponding area according to the depth map of the projection surface. The step of calibrating the corresponding area of the projection area and the depth sensing area comprises the following step: projecting at least two calibration patterns onto the projection surface according to a plurality of predetermined locations of a projection device and a depth sensing device; capturing an image of the projection surface and detecting a plurality of locations of the at least two calibration patterns in the image; obtaining a plurality of locations of the at least two calibration patterns in the depth map; adjusting a projection location of the at least two calibration patterns according to the plurality of locations of the at least two calibration patterns in the image and the depth map to obtain at least two anchor points in the depth map, wherein the at least two anchor points are within the projection area and the depth sensing area; and calibrating the corresponding area of the projection area and the depth sensing area according to the at least two anchor points. The step of adjusting the interactive content within the corresponding area according to the depth map of the projection surface comprises the following step: projecting

the interactive content within the corresponding area of the depth sensing area; deforming the interactive content according to the depth map of the projection surface; and adjusting a relative position of the interactive content according to the depth map of the projection surface.

According to another embodiment of the disclosure, a non-planar surface projecting system is provided. The non-planar surface projecting system comprises a depth sensing device, a projecting device, an image capturing device and an auto-calibration device. The depth sensing device is configured to estimate a depth map of a projection surface. The projecting device is configured to project at least two calibration patterns and an interactive content onto the projection surface. The projecting device and the depth sensing device project the at least two calibration patterns onto the projection surface according to a plurality of predetermined locations of a depth sensing device, and the interactive content is adjusted and projected by an auto-calibration device. The image capturing device is configured to capture an image of the projection surface. The auto-calibration device is configured to calibrate a corresponding area of a projection area and a depth sensing area, and adjust the interactive content within the corresponding area according to the depth map of the projection surface. The auto-calibration device comprises a corresponding area correcting unit and an interactive content adjusting unit, the corresponding area correcting unit is configured to detect the at least two calibration patterns in the image and obtain a plurality of locations of the at least two calibration patterns in the depth map, and the interactive content adjusting unit is configured to adjust the interactive content in corresponding area according to the depth map of the projection surface. The auto-calibration device is further configured to adjust a projection location of the at least two calibration patterns according to the plurality of locations in the image and depth map of the at least two calibration patterns to obtain at least two anchor points of the depth map, wherein the at least two anchor points are within the projection area and the depth sensing area, and obtain the corresponding area of the projection area and the depth sensing area according to the at least two anchor points.

According to another embodiment of the disclosure, an auto-calibration device is provided. The auto-calibration device is connected to a depth sensing device, a projecting device, and an image capturing device. The depth sensing device is configured to estimate a depth map of a projection surface. The projecting device is configured to project at least two calibration patterns onto the projection surface according to a projection location. The image capturing device is configured to capture an image of the projection surface. The auto-calibration device comprises a corresponding area correcting unit and an interactive content adjusting unit. The area corresponding area correcting unit comprises a detecting unit, a calculating unit, a position adjusting unit, an area setting unit, an image scaling unit, an image masking unit, an image segmenting unit, an image moving unit, and an image combining unit. The detecting unit is configured to detect a plurality of locations of the at least two calibration patterns in the image. The calculating unit is configured to obtain a plurality of locations of the at least two calibration patterns in the depth map. The position adjusting unit is configured to adjust the projection location of the at least two calibration patterns according to the plurality of locations in the image and the depth map of the at least two calibration patterns to obtain at least two anchor points in the depth map. The at least two anchor points are within the projection area and the depth sensing area. The area setting unit is configured to obtain a calibrated corresponding area of the projection area and the depth sensing area according to the at least two anchor points. The interactive content adjusting unit comprises an image scaling unit, an image masking unit, an image masking unit, an image segmenting unit, an image moving unit, and an image combining unit. The image scaling unit is configured to zoom in or zoom out the interactive content according to the corresponding area of the projection area and the depth sensing area. The image masking unit is configured to mask the interactive content beyond the corresponding area when the projection area is larger than the depth sensing area. The image deforming unit is configured to deforming the interactive content according to the depth map of the projection surface. The image segmenting unit is configured to distinguish foreground objects from the background. The image moving unit is configured to adjust a relative position of a projected character or pattern according to the depth map of the projection surface when an object is placed on the projection surface. The image combining unit is configured to combine the processing results of the image scaling unit, the image masking unit, the image deforming unit, the image segmenting unit, and the image moving unit, and transmit combined processing results to the projecting device.

The foregoing will become better understood from a careful reading of a detailed description provided herein below with appropriate reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a non-planar surface projecting system according to an embodiment of the disclosure.

FIG. **2** is a schematic view of a non-planar surface projecting system applied to a non-planar projection surface according to an embodiment of the disclosure.

FIG. **3** is a schematic diagram of a corresponding area correcting unit according to an embodiment of the disclosure.

FIG. **4** is a schematic diagram of an interactive content adjusting unit according to an embodiment of the disclosure.

FIG. **5** is a flow chart of the corresponding area correcting method according to an embodiment of the disclosure.

FIG. **6** is a flow chart of the interactive content adjusting method according to an embodiment of the disclosure.

FIG. **7**A to FIG. **7**C illustrate schematic views of the steps in FIG. **5**, respectively.

FIG. **8** is a schematic view of the calibration patterns according to another embodiment of the disclosure.

FIG. **9** is a schematic view of the calibration patterns according to still another embodiment of the disclosure.

FIG. **10** is a schematic view of the calibration patterns according to another embodiment of the disclosure.

FIG. **11** is a schematic view of the calibration patterns according to still another embodiment of the disclosure.

DETAILED DESCRIPTION OF DISCLOSED EMBODIMENTS

Below, exemplary embodiments will be described in detail with reference to accompanying drawings so as to be easily realized by a person having ordinary knowledge in the art. The inventive concept may be embodied in various forms without being limited to the exemplary embodiments set forth herein. Descriptions of well-known parts are omitted for clarity, and like reference numerals refer to like elements throughout.

Please refer to FIG. **1** and FIG. **2**. FIG. **1** is a schematic diagram of a non-planar surface projecting system **100** according to an embodiment of the disclosure. FIG. **2** is a schematic view of the non-planar surface projecting system **100** applied to a non-planar surface of a projection surface **900** according to an embodiment of the disclosure. The non-planar surface projecting system **100** may be, but not limited to a projector, a smartboard, a smart wall lamp, a smart table lamp, a smart table, a smart furnace or a smart stove. The smartboard, the smart wall lamp, the smart table lamp, the smart table, the smart furnace or the smart stove may carry on an interactive projection with the user's palm or limb in the foreground. The projection may be carried onto a non-planar surface of the projection surface **900**. An auto-calibration of the non-planar surface projecting system **100** in the embodiment is performed by using a depth capturing technology, a projecting technology, an image capturing technology and an auto control technology, so as to the non-planar surface projecting system **100** may carry on an projection according to various changes of the non-planar surface of the projection surface **900** and avoid a distortion of a projection image. In the interactive projection, the non-planar surface projecting system **100** may avoid the protrusion of the projection surface **900** being wrongly identified as an object of an interactive operation (for example, the palm or limb).

Referring to FIG. **1**, the non-planar surface projecting system **100** comprises a depth sensing device **110**, a projecting device **120**, an image capturing device **130** and an auto-calibration device **140**. The depth sensing device **110**, for example, a dual-camera, a structured-light depth sensing device, a Time of Flight depth sensing device, or a LiDAR depth sensing device, is used to estimate a depth map of a projection surface. The projecting device **120**, for example, a cathode ray tube projector (CRT projector), a liquid crystal display (LCD projector), or a digital light processing projector (DLP projector), is used to project an image and calibration patterns.

The image capturing device **130**, for example, a color camera or a monochrome camera, is used to capture an image. The auto-calibration device **140**, for example, a chip, a circuit, a circuit board or a storage medium for storing program codes, is used to perform each of calculation procedure(s), determination procedure(s), detection procedure(s) and control procedure(s) and is configured to calibrate a corresponding area of a projection area and a depth sensing area. The auto-calibration device **140** comprises a corresponding area correcting unit **141** and an interactive content adjusting unit **142**. The corresponding area correcting unit **141** is configured to calibrate the corresponding area of the projection area and the depth sensing area. The interactive content adjusting unit **142** based on a control signal CM**2** is configured to adjust an interactive content within the corresponding area according to the depth map of the projection surface. Please refer to the corresponding area correcting unit **141** in FIG. **3**. The corresponding area correcting unit **141** comprises a detecting unit **141***a*, a calculating unit **141***b*, a position adjusting unit **141***c*, a area setting unit **141***d*. The detecting unit **141***a* is configured to perform various detection procedures on the image captured by the image capturing device **130**.

The calculating unit **141***b* is configured to perform various calculation procedures. The position adjusting unit **141***c* is configured to perform various position adjusting procedures.

The area setting unit **141***d* is configured to set a calibrated corresponding area of the projection area and the depth sensing area. Please refer to the interactive content adjusting unit **142** in FIG. **4**. The interactive content adjusting unit **142** comprises an image scaling unit **142***a*, an image masking unit **142***b*, an image deforming unit **142***c*, an image segmenting unit **142***d*, an image moving unit **142***e*, an image combining unit **142***f*. The image scaling unit **142***a* is configured to zoom in or zoom out the interactive content according to the corresponding area of the projection area and the depth sensing area. The image masking unit **142***b* is configured to mask the interactive content beyond the corresponding area when the projection area is larger than the depth sensing area. The image deforming unit **142***c* is configured to deforming the interactive content according to the depth map of the projection surface. The image segmenting unit **142***d* is configured to distinguish background objects from a foreground according to the depth map of the projection surface. The image moving unit **142***e* is configured to adjust a relative position of a projected character or pattern according to the depth map of the projection surface when a foreground is determined by the image segmenting unit **142***d* on the projection surface. The image combining unit **142***f*, is configured to combine the processing results of the image scaling unit **142***a*, the image masking unit **142***b*, the image deforming unit **142***c*, the image segmenting unit **142***d*, and the image moving unit **142***e*, and transmit the combined processing results to the projecting device **120**.

Please refer to FIG. **1** to FIG. **3**, FIG. **5**, and FIG. **7**A to FIG. **7**C. FIG. **5** illustrates a flow chart of a corresponding area correcting method of an auto-calibration method for the non-planar surface projecting system **100** according to an embodiment of the disclosure. FIG. **7**A to FIG. **7**C illustrate schematic views of the steps of FIG. **5**, respectively. In the step S**110**, align the depth sensing device **110** with the image capturing device **130**. In this step, the depth sensing device **110** and the image capturing device **130** may take pictures of a calibrated checkerboard and obtain a 3D spatial information.

In the step S**120**, as illustrated in FIG. **2**, the depth sensing device **110** estimates a depth map DM of a projection surface **900** (illustrated in FIG. **7**A). In other embodiment, the depth sensing device **110** builds a three-dimensional mesh (3D mesh). The 3D mesh may be, but not limit to a 3D triangular mesh or a 3D rectangular mesh. The depth sensing device **110** may project an infrared light onto the non-planar surface of the projection surface **900**, and obtain a depth map or build a 3D mesh according to the refracted infrared light.

In the step S**130**, as illustrated in FIG. **2**, the projecting device **120** projects at least two calibration patterns (for example, calibration patterns P**11**, P**12**, P**13**, P**14**) onto the projection surface **900** according to a plurality of predetermined locations of a projecting device and a depth sensing device. The calibration patterns P**11**, P**12**, P**13**, and P**14** are different. Different shadings represent different colors, and the color arrangements of the calibration patterns P**11**, P**12**, P**13**, and P**14** are different. Therefore, the calibration patterns P**11**, P**12**, P**13**, and P**14** may be identified by the color arrangements.

In the step S**140**, as illustrated in FIG. **2**, the image capturing device **130** captures an image IM of the projection surface **900**. The detecting unit **141***a* of the corresponding area correcting unit **141** may detect the locations of the calibration patterns P**11**, P**12**, P**13**, and P**14** in the image IM. In this step, the detecting unit **141***a* may identify the locations of the calibration patterns P**11**, P**12**, P**13**, and P**14** by using a template matching algorithm.

In the step S**150**, as illustrated in FIG. **7**A, the calculating unit **141***b* of the corresponding area correcting unit **141** is configured to obtain a plurality of locations of the calibration patterns P**11**, P**12**, P**13**, and P**14** in the depth map. In other embodiment, the locations for the calibration patterns P**11**, P**12**, P**13**, and P**14** in the image IM are identified by using a 3D spatial conversion matrix of the 3D mesh TM.

In the step S**160**, the position adjusting unit **141***c* of the corresponding area correcting unit **141** is configured to transmit a control signal CM**1***a* to adjust the projection location of the calibration patterns P**11**, P**12**, P**13** and P**14** according to the locations of the calibration patterns P**11**, P**12**, P**13** and P**14** in the image and the depth map to obtain at least two anchor points in the depth map. Then, the position adjusting unit **141***c* is configured to transmit a control signal CM**1***b* to the image capturing device **130** and capture the image IM of the projection surface **900**. The detecting unit **140***a* is configured to detect the calibration patterns P**11**, P**12**, P**13**, and P**14** again and obtain the locations of the calibration patterns P**11**, P**12**, P**13**, and P**14** in the image IM, respectively. The step S**160** is repeated until the anchor points of the depth map DM are obtained. The anchor points are within the projection area and the depth sensing area.

For example, the calibration patterns P**13**, P**14** are located outside the depth map DM as illustrated in FIG. **7**A, the projecting device **120** is configured to move the calibration pattern P**13** toward a projection central point C**0** or a projection central axis (for example, a horizontal projection central axis H**0** or a vertical projection central axis V**0**).

As illustrated in FIG. **7**B, the calibration pattern P**13** is stopped moving until the calibration pattern P**13** is completely moved into the depth map DM and is identified. At this time, the position adjusting unit **141***c* may obtain an anchor point E**13**. Similarly, as illustrated in FIG. **7**B to FIG. **7**C, the projecting device **120** is configured to move the calibration pattern P**14** located outside the depth map DM toward the projection central point C**0**, the horizontal projection central axis H**0** or the vertical projection central axis V**0**. The calibration pattern P**14** is stopped moving until the calibration pattern P**14** is completely moved into the depth map DM and is identified. At this time, the position adjusting unit **141***c* may obtain an anchor point E**14**.

As illustrated in FIG. **7**B to FIG. **7**C, the projecting device **120** is configured to move the calibration patterns P**11** and P**12** located inside the depth map DM outward the projection central point C**0**, the horizontal projection central axis H**0** or the vertical projection central axis V**0**. The calibration patterns P**11**, P**12** are stopped moving until the calibration patterns P**11** and P**12** are partially moved out of the depth map DM and are identified. At this time, the position adjusting unit **141***c* may obtain two anchor points E**11** and E**12**.

In the step S**170**, the area setting unit **141***d* of the corresponding area correcting unit **141** is configured to locate a corresponding area R**11** of the projection area and the depth sensing area according to the at least two anchor points E**11**, E**12**, E**13**, and E**14**. The corresponding area R**11** is the maximum inscribed rectangle of the anchor points E**11**, E**12**, E**13** and E**14**.

In the step S**180**, the area setting unit **141***d* of the corresponding area correcting unit **141** is configured to output the corresponding area R**11** of the corrected projection area and the depth sensing area to the interactive content adjusting unit **142**.

FIG. **6** is a flow chart of the interactive content adjusting method of the non-planar surface projecting system **100** according to an embodiment of the disclosure. In step S**210**, determine whether the ratio of the corresponding area R**11** of the projection area is consistent to the corresponding area R**11** of the depth sensing area. If the ratio of the corresponding area R**11** of the projection area is inconsistent to the corresponding area R**11** of the depth sensing area, the step S**220** is performed to scale the image. If the ratio of the corresponding area R**11** of the projection area is consistent to the corresponding area R**11** of the depth sensing area, the step S**230** is performed to determine whether the projection area offsets from the depth sensing area. If the projection area offsets from the depth sensing area, the step S**240** is performed to obscure the interactive content beyond the corresponding area R**11**. If the projection area does not offset from the depth sensing area, the step S**250** is performed to determine whether the variation of the depth value on the projection surface is greater than a threshold. If the variation of the depth value of the projection surface is greater than a threshold, it represents the projection surface is a non-planar surface. Thus, the step S**260** is performed to deform the interactive content. If the variation of the depth value of the projection surface depth value is less than or equal to a threshold, it represents the projection surface is regarded as a planar surface. Thus, it is not necessary to deform the interactive content. The step S**270** is performed to distinguish the foreground objects from the background according to the depth map of the projection surface. Next, step S**280** is performed to adjust a relative position of the interactive content according to the depth map of the projection surface, and the interactive content of the projection is prevented from interfering with the object placed on the projection surface. Finally, combine the processing results of step S**220**, step S**240**, step S**260** and step S**280** in step S**290**, and then transmit the combined results to the projecting device **120**. This allows the non-planar surface projecting system **100** to automatically correct the corresponding area R**11** of the projection area and the depth sensing area and adjust the interactive content according to the depth information of the projection surface **900** within the corresponding area R**11**. The non-planar surface projecting system **100** may avoid the distortion of a projection image or avoid the protrusion of the projection surface **900** being wrongly identified as an interactive operation (for example, the palm or limb).

FIG. **8** is a schematic view of the calibration patterns P**21**, P**22**, P**23**, and P**24** according to another embodiment of the disclosure. In the embodiment, the calibration patterns P**21**, P**22**, P**23**, and P**24** projected by the projecting device **120** in the step S**130** may have the same shape but different colors. The image capturing device **130** may be a color camera. In step S**140**, the detecting unit **141***a* of the corresponding area correcting unit **141** may obtain the calibration patterns P**21**, P**22**, P**23**, and P**24** by using color comparison.

FIG. **9** is a schematic view of calibration patterns P**31**, P**32**, P**33**, and P**34** according to still another embodiment of the disclosure. In the embodiment, the calibration patterns P**31**, P**32**, P**33**, and P**34** projected by the projecting device **120** in the step S**130** may have the same color but different shapes. The image capturing device **130** may be a monochrome camera. In step S**140**, the detecting unit **141***a* of the corresponding area correcting unit **141** may obtain the calibration patterns P**31**, P**32**, P**33**, and P**34** by using shape comparison.

FIG. **10** is a schematic view of calibration patterns P**41**, P**42** according to another embodiment of the disclosure. In the embodiment, a number of the calibration patterns are two. In the step S**170**, the position adjusting unit **141***c* of the corresponding area correcting unit **141** is configured to move the calibration patterns P**41** and P**42** and use the found anchor points E**41** and E**42** of the calibration patterns P**41** and P**42** as the diagonal of a rectangle to locate a rectangular corresponding area R**41** of a projection area and a depth sensing area.

FIG. **11** is a schematic view of calibration patterns P**51** and P**52** according to still another embodiment of the disclosure. In the embodiment, a number of the calibration patterns are two. In the step S**170**, the position adjusting unit **141***c* of the corresponding area correcting unit **141** is configured to move the calibration patterns P**51** and P**52** and use the found anchor points E**51** and E**52** of the calibration patterns P**51** and P**52** as a diameter D**51** of a circle, and take the central point of diameter D**51** as a centre C**51** of the circle to obtain a circular corresponding area R**51** of a projection area and a depth sensing area.

According to the various embodiments described above, through the steps of projection and moving of the calibration patterns, the corresponding area of the projection area and the depth sensing area may be corrected by the projected calibration patterns and the operation of moving the calibration pattern, and within the corresponding area, the interactive content is adjusted according to the depth map of the projection surface. So that the non-planar surface projecting system can project the interactive content within the corresponding area of the projection area and the depth sensing area. The non-planar surface projecting system may deform the interactive content according to the depth map of a projection surface. When the object is placed on the surface, the non-planar surface projecting system may adjust the relative position of the interactive content based on the depth map of the projection surface.

It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure. It is intended that the specification and examples be considered as exemplary embodiments only, with a scope of the disclosure being indicated by the following claims and their equivalents.

What is claimed is:

1. An auto-calibration method for a non-planar surface projecting system, comprising:

estimating a depth map of a projection surface;

calibrating a corresponding area of a projection area and a depth sensing area, wherein calibrating the corresponding area of the projection area and the depth sensing area comprises:

projecting at least two calibration patterns onto the projection surface according to a plurality of predetermined locations of a projecting device and a depth sensing device;

capturing an image of the projection surface and detecting a plurality of locations of the at least two calibration patterns in the image;

obtaining a plurality of locations of the at least two calibration patterns in the depth map;

adjusting a projection location of the at least two calibration patterns according to the plurality of locations in the image and the depth map of the at least two calibration patterns to obtain at least two anchor points in the depth map, wherein the at least two anchor points are within the projection area and the depth sensing area; and

calibrating the corresponding area of the projection area and the depth sensing area according to the at least two anchor points; and

adjusting an interactive content within the corresponding area according to the depth map of the projection surface, wherein adjusting the interactive content within the corresponding area according to the depth map of the projection surface comprises:

projecting the interactive content within the corresponding area of the depth sensing area;

deforming the interactive content according to the depth map of the projection surface; and

adjusting a relative position of the interactive content according to the depth map of the projection surface.

2. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein adjusting the projection location is performed and said calibration patterns in the depth map are partially moved out of the depth map, or said calibration patterns outside the depth map are fully moved into the depth map to obtain the at least two anchor points.

3. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein said calibration patterns located outside the depth map are moved toward a projection central point or a projection central axis, in performing the step of adjusting the projection location.

4. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein said calibration patterns located inside the depth map are moved outward a projection central point or a projection central axis, in performing the step of adjusting the projection location.

5. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein all of said at least two calibration patterns are different.

6. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein all color arrangements for all of said at least two calibration patterns are different.

7. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein all shapes of all of said at least two calibration patterns are different.

8. The auto-calibration method for a non-planar surface projecting system as recited in claim **1**, wherein a number of said at least two calibration patterns are four, and the calibrated corresponding area is a maximum inscribed rectangle.

9. A non-planar surface projecting system, comprising:

a depth sensing device, estimating a depth map of a projection surface;

a projecting device, projecting at least two calibration patterns and an interactive content onto the projection surface, wherein the projecting device and the depth sensing device project the at least two calibration patterns onto the projection surface according to a plurality of predetermined locations of a depth sensing device, and the interactive content is adjusted and projected by an auto-calibration device;

an image capturing device, capturing an image of the projection surface; and

an auto-calibration device, calibrating a corresponding area of a projection area and a depth sensing area according to at least two anchor points, and adjusting the interactive content within the corresponding area according to the depth map of the projection surface;

wherein the auto-calibration device comprises a corresponding area correcting unit and an interactive content adjusting unit, the corresponding area correcting unit is configured to detect a plurality of locations of the at least two calibration patterns in the image and obtain a plurality of locations of the at least two calibration patterns in the depth map, and the interactive content adjusting unit is configured to adjust the interactive content according to the depth map of the projection surface;

wherein the auto-calibration device is configured to adjust a projection location of the at least two calibration patterns according to the plurality of locations in the image and the depth map of the at least two calibration patterns within the projection area and the depth sensing area to obtain at least two anchor points in the depth map, and locate the corresponding area of the projection area and the depth sensing area according to the at least two anchor points.

10. The non-planar surface projecting system as recited in claim **9**, wherein the corresponding area correcting unit partially moves said calibration patterns in the depth map out of the depth map, or fully moves said calibration patterns outside the depth map into the depth map to obtain said anchor points.

11. The non-planar surface projecting system as recited in claim **9**, wherein the projecting device is controlled by the corresponding area correcting unit to move said calibration patterns toward a projection central point or a projection central axis.

12. The non-planar surface projecting system as recited in claim **9**, wherein the projecting device is controlled by the corresponding area correcting unit to move said calibration patterns outward a projection central point or a projection central axis.

13. The non-planar surface projecting system as recited in claim **9**, wherein all of said at least two calibration patterns are different.

14. The non-planar surface projecting system as recited in claim **9**, wherein the image capturing device is a color camera, and all color arrangements for all of said at least two calibration patterns are different.

15. The non-planar surface projecting system as recited in claim **9**, wherein the image capturing device is monochrome camera, and all shapes of all of said at least two calibration patterns are different.

16. The non-planar surface projecting system as recited in claim **9**, wherein a number of the at least two calibration patterns are four, and the calibrated corresponding area is a maximum inscribed rectangle.

17. A auto-calibration device, connected to a depth sensing device, a projecting device, and an image capturing device, wherein the depth sensing device is configured to estimate a depth map of a projection surface, the projecting device is configured to project at least two calibration patterns and an interactive content onto the projection surface according to a projection location, the image capturing device is configured to capture an image of the projection surface, and the auto-calibration device comprises a corresponding area correcting unit and an interactive content adjusting unit, wherein the corresponding area correcting unit comprises:

a detecting unit, detecting the at least two calibration patterns of the image;

a calculating unit, obtaining a plurality of locations of the at least two calibration patterns in the depth map;

a position adjusting unit, adjusting a projection location of the at least two calibration patterns according to the plurality of locations of the at least two calibration patterns in the depth map to obtain at least two anchor points, wherein the at least two anchor points are within a projection area and a depth sensing area; and a area setting unit, locate the corresponding area of the projection area and the depth sensing area according to the at least two anchor points;

wherein the interactive content adjusting unit comprises:

an image scaling unit, zooming in or zooming out the interactive content according to the corresponding area of the projection area and the depth sensing area;

an image masking unit, masking the interactive content beyond the corresponding area when the projection area is larger than the depth sensing area;

an image deforming unit, deforming the interactive content according to the depth map of the projection surface;

an image segmenting unit, distinguishing foreground objects from a background;

an image moving unit, adjusting a relative position of a projected character or pattern according to the depth map of the projection surface when an object is placed on the projection surface; and

an image combining unit, combining processing results of the image scaling unit, the image masking unit, the image deforming unit, the image segmenting unit, and the image moving unit, and transmitting combined processing results to the projecting device.

18. The auto-calibration device as recited in claim **17**, wherein the position adjusting unit partially moves said calibration patterns in the depth map out of the depth map, or fully moves said calibration patterns outside the depth map into the depth map to obtain said anchor points.

19. The auto-calibration device as recited in claim **17**, wherein the projecting device is controlled by the position adjusting unit to move said calibration patterns toward a projection central point or a projection central axis.

20. The auto-calibration device as recited in claim **17**, wherein the projecting device is controlled by the position adjusting unit to move said calibration patterns outward a projection central point or a projection central axis.

21. The auto-calibration device as recited in claim **17**, wherein all of said at least two calibration patterns are different.

22. The auto-calibration device as recited in claim **17**, wherein the image capturing device is a color camera, and all color arrangements for all of said at least two calibration patterns are different.

23. The auto-calibration device as recited in claim **17**, wherein the image capturing device is a monochrome camera, and the shapes of all of said at least two calibration patterns are different.

24. The auto-calibration device as recited in claim **17**, wherein a number of said at least two calibration patterns are four, and said calibrated corresponding area is a maximum inscribed rectangle.

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